Application Note

Structural vibration monitoring of a wind turbine tower with a multibeam laser Doppler vibrometer

1. Introduction

This application note describes the measurement and analysis of structural vibrations in a real wind turbine tower using the Ommatidia Q1 multi-channel lase Doppler vibrometer. The campaign was conducted in Las Navas del Marqués (Ávila, Spain). The objective was to characterise the dynamic behaviour of the tower under both operational (moving rotor) and non-operational (static rotor) conditions, and to demonstrate the capability of the Q1 instrument to resolve modal content across multiple spatial channels simultaneously.

Structural health monitoring of wind turbine towers and their foundations requires accurate identification of vibration modes and their amplitudes. Variations between static and rotating conditions provide insight into aerodynamic excitation, drivetrain coupling, and tower–blade interaction effects. The Ommatidia Q1 enables non-contact, distributed vibration measurement over 128 channels, allowing spatially resolved modal analysis **without assembling physical sensors on the structure and complex instrumentation effort**. It is important to mention that simultaneous multichannel capability is key for Operational Modal Analysis (OMA) application since we can capture the effect of transient excitation (wind).

2. The Q1 laser Doppler vibrometer

The equipment used for this test was the Ommatidia LiDAR Q1 Laser Doppler vibrometer based on FMCW Laser RADAR technology (*Frequency Modulated Continuous Wave*). The Q1 has two operating modes:

Laser Doppler vibrometer mode: measures the velocity or displacement of a surface without contact.

Metrology mode: measures the distance to the sensor and generates a point cloud

This system features multichannel coherent detection, consisting of **128 simultaneous laser beams** for signal acquisition. Thanks to the use of a dedicated photonic integrated circuit (PIC), Q1 analyzes multiple optical channels in parallel, enabling the measurement of transient phenomena such as impacts and OMA.

Figure 1: Ommatidia's Q1 LDV

Figure 2: left: field view from Q2. The green dotted line represents the 65 measuring points. Right: by scanning the azimuthal angle, the full-field view measurement is obtained

3. Measurement Configuration

The Ommatidia Q1 system was deployed in several minutes to measure structural vibrations simultaneously across 128 independent channels (laser spots) along the front generatrix of the turbine tower (Figure 3). The distance to the surface of the tower was between **50 and 70m.** The instrument accumulated the measurement **during just 2 seconds**, indicating that the sensitivity is good enough. The instrument records instantaneous velocity data in units of millimetres per second.

Figure 3: deployment of Q1 LDV in the field. The dotted line is superimposed to show the measuring points

For each measurement condition (working/static turbine), the following datasets were obtained and analysed:

- The instantaneous velocity for all channels as a function of time.
- The averaged velocity across channels
- The Fourier transform of the averaged velocity signal to identify dominant vibration modes.

Representative channel-level data were also extracted to illustrate spatial variability. In the moving turbine condition, channels 37, 43, 53, and 64 were analysed. In the static turbine condition, channels 44, 64, 68, and 69 were examined.

4. Moving Turbine Condition

Under operational conditions, the turbine rotor was rotating and aerodynamic loading was present. The normalised velocity map across all 128 channels (Figure 4) shows coherent banded structures, indicating spatially correlated vibration patterns along the monitored section. The amplitude distribution reveals elevated activity across several channel groups, suggesting excitation of multiple structural modes.

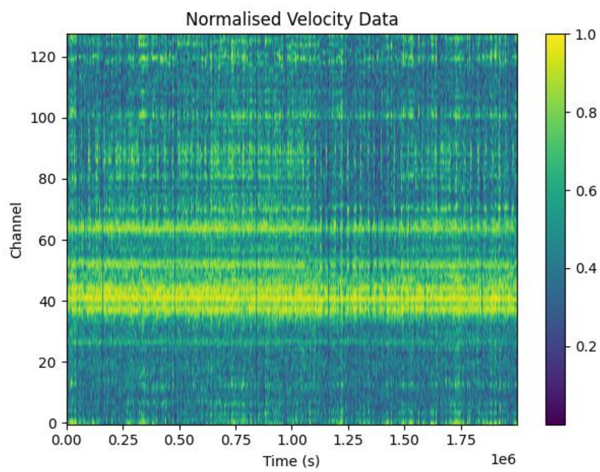

Figure 4: Normalised velocity for each channel and time for the moving turbine condition

The averaged velocity time series (Figure 5, left) exhibits fluctuations with peak amplitudes on the order of ±0.01 mm/s. The temporal variability reflects combined contributions from rotor-induced excitation and structural resonances.

The Fourier transform of the averaged velocity (Figure 5, right) highlights a dominant low-frequency peak below 1 Hz and additional components extending toward approximately 6 Hz. The strong low-frequency component is consistent with fundamental tower bending or global structural modes driven by rotor rotation. Secondary peaks indicate higher-order structural or blade-related modes.

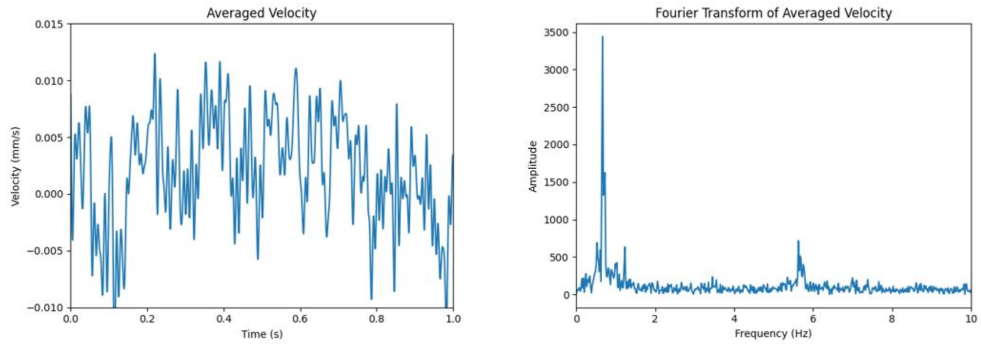

Figure 5: averaged velocity across channels (left) and its FFT (right) for the moving turbine condition

Analysis of individual channels confirms the presence of consistent modal frequencies across spatial locations, with amplitude variations reflecting modal shape distribution. Channels 37, 43, 53, and 64 all display pronounced low-frequency peaks in their respective spectra, demonstrating coherent global behaviour.

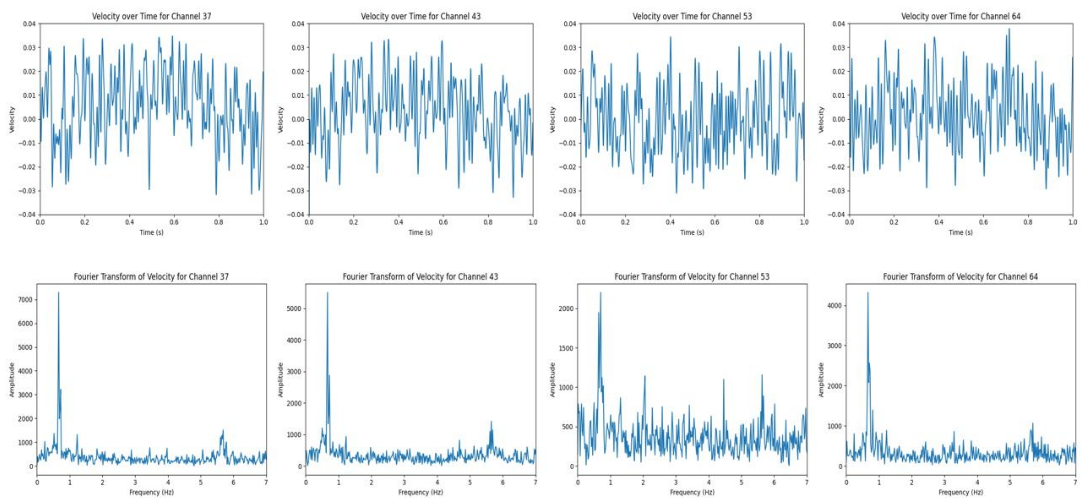

Figure 6: velocities over time (top row) and FFT (bottom row) for selected channels for the moving turbine condition

5. Static Turbine Condition

In the static configuration, the rotor was not rotating, and aerodynamic forcing was absent. The normalised velocity map shows (Figure 7) reduced overall amplitude compared to the moving condition, while maintaining visible spatial structure. This indicates that ambient excitation, such as wind loading on the tower or environmental disturbances, continues to excite structural modes and is a proof of the ability of the Q1 LDV to measure at long range (tens of meters) without external excitation. This is important because when performing vibration measurements in civil engineering structures and buildings, one frequently needs to integrate the signal for several hours.

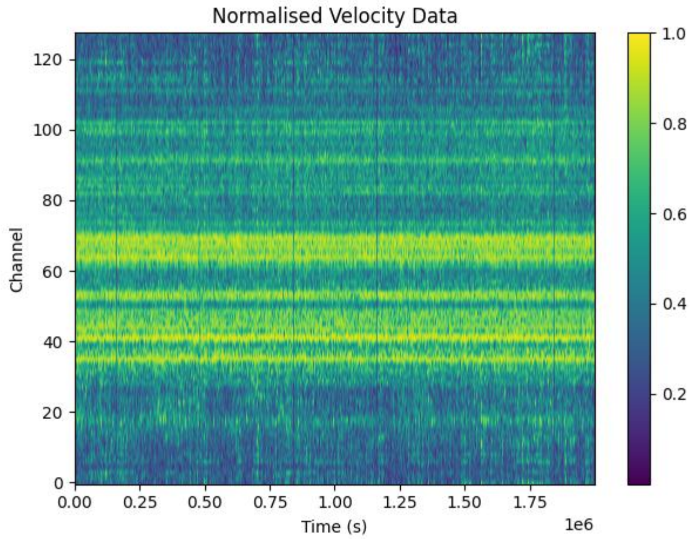

Figure 7: Normalised velocity for each channel and time for the static turbine condition

The averaged velocity time series under static conditions exhibits (Figure 8, left) lower amplitude fluctuations, typically within ±0.005 mm/s. This reduction confirms the contribution of rotor dynamics to vibration amplitude during operation.

The Fourier transform of the averaged velocity (Figure 8, right) reveals a dominant peak at low frequency, similar to the moving case, but with significantly lower magnitude. The persistence of this peak confirms that it corresponds to an intrinsic structural mode rather than purely operational excitation. Higher-frequency components are present but attenuated relative to the moving condition.

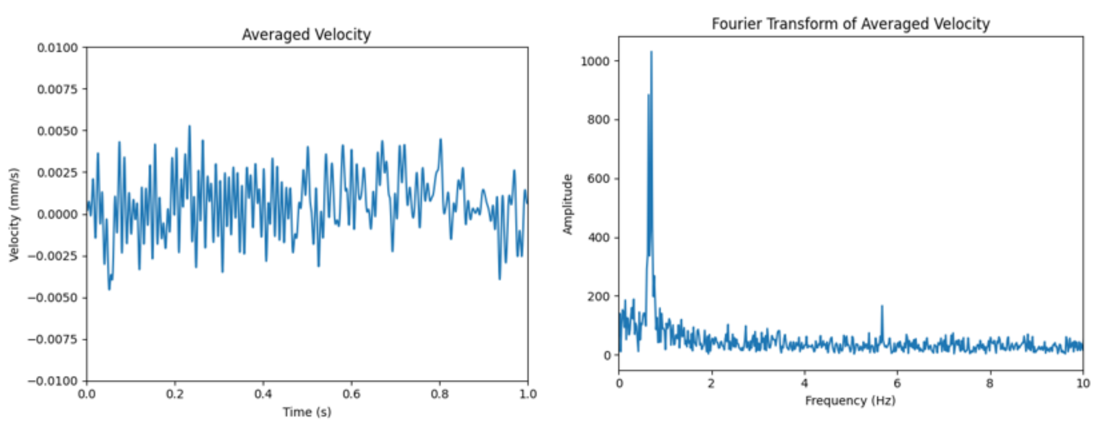

Figure 8: averaged velocity across channels (left) and its FFT (right) for the static turbine condition

Representative channels 44, 64, 68, and 69 show consistent spectral characteristics, with clear identification of the primary low-frequency resonance. Spatial amplitude variation is observable, consistent with modal shape distribution along the structure.

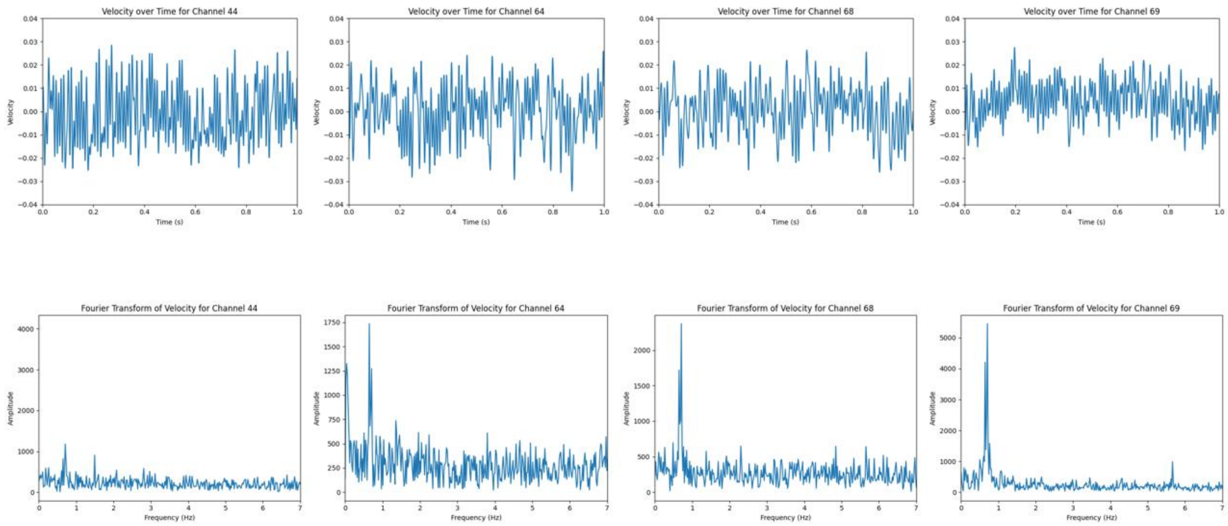

Figure 9: velocities over time (top row) and FFT (bottom row) for selected channels for the moving turbine condition

6. Comparison Between Static and Moving Conditions

A direct comparison of static and moving datasets demonstrates the influence of rotor operation on structural dynamics. The moving condition exhibits increased vibration amplitude across nearly all channels, indicating additional excitation energy introduced by aerodynamic forces and drivetrain coupling.

The averaged velocity spectrum under rotation shows a substantial amplification of the dominant low-frequency mode, as well as clearer excitation of secondary modes up to approximately 6–7 Hz. In contrast, the static spectrum is dominated by the fundamental mode with reduced higher-frequency content.

The spatially resolved normalised velocity maps illustrate stronger modal contrast during operation, suggesting improved signal-to-noise ratio for operational modal analysis. The Q1 system captures both global and local dynamic behaviour, enabling differentiation between ambient structural modes and rotor-induced responses.

7. Technical Implications and Conclusion

These results demonstrate that the Ommatidia Q1 provides high-resolution, multi-channel vibration measurement suitable for wind turbine tower structural assessment. The ability to measure 128 channels simultaneously allows detailed spatial modal identification without sensor installation on the structure. Moreover, the **ease of deployment of the instrument** is key for practical purposes and productivity of inspection campaigns.

The comparison between static and operational conditions enables separation of intrinsic structural resonances from operational excitation effects. This capability is essential for condition monitoring, early fault detection, and validation of structural models.

The non-contact LDV-based approach **eliminates complex instrumentation tasks** associated with accelerometers and simplifies deployment in field environments. The system is particularly well suited for modal analysis, commissioning verification, and long-term structural health monitoring of wind energy assets.

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